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Behavior of Aluminum Alloy Castings under Different Pouring Temperatures and Speeds

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ABSTRACT

This investigation studied the effect of varying magnesium percentage compositions in aluminium - magnesium alloy at a specific pouring rate of 2.5 cm/sec and a pouring temperature of 760°C. The sand cast specimens were produced in the following magnesium alloy percentage compositions; 3.33%, 6.67%, 10.00%, 13.33% and 16.67%. The specimens were subsequently tested for quality, and properties such as hardness, compressive strength and metallographic examinations were considered. Observations and results indicated that there was reduction in grain size as the percentage composition of magnesium increased from 3.33% to 13.33%, on the contrary the hardness and compressive strength improved with increasing percentage composition of the magnesium alloy. In the range of magnesium additions tried, the sample containing 13.33% magnesium alloy seems to be the most favorable alloy in terms of compressive strength, hardness and grain size in the sand cast condition.

Keywords

Pouring Temperature; Pouring Speed; Compressive Strength; Hardness; metallographic Examination; Grain Size; Percentage Composition

1. INTRODUCTION

The transportation industry, and in particular the automotive industry, is imposed to seek light materials in the development of robust parts. The global production of aluminium and magnesium alloys has therefore increased, and the consumption of aluminium concurrently exceeds the existing production capacity of primary metal. It is therefore necessary to exploit, or invent, economically sustainable processes that can give light weight products with integrated functions that fulfil the requirements for recycling and fuel consumption regulations. Varying the percentage composition of magnesium in the aluminium alloy is a method that well suits to these demands.

To an engineer, the knowledge and understanding of casting parameters in casting different metals and alloys is as significant as the cast products. Metal casting is by definition any process of melting metal and pouring them into mould in order to produce the required shapes. Specific casting parameters such as pouring temperatures, rate of pouring, fluidity and composition of metals are of topmost importance for consideration if sound casting is to be achieved.

Aluminium is the world's most abundant metal and thus the third most common element comprises 8% of the earth's crust. The versatility of aluminium makes it the most widely used metal after steel. It is derived from the mineral bauxite. Bauxite is converted to aluminium oxide (alumina) via the Bayer Process. The alumina is then converted to aluminium metal using electrolytic cells and the Hall-Heroult Process.

Worldwide demand for aluminium is around 29 million tons per year. About 22 million tons is new aluminium and 7 million tons is recycled aluminium scrap. The use of recycled aluminium is economically and environmentally compelling. It takes 14,000 kWh to produce 1 tonne of new aluminium. Conversely it takes only 5% of this to re-melt and recycle one tonne of aluminium.

It has been observed (Pius, 2000) that melting and pouring conditions directly or indirectly affects such mechanical properties of cast materials as: hardness, percentage elongation, percentage reduction in diameter, toughness and so on. For instance an investigation on pouring rate of some ferrous metals (Warrendale, 1981) revealed that metals such as steels have very high freezing rate compared to most other alloys castings. The optimum pouring speed is also found to be a function of the casting size and shape.

The knowledge of melting temperature of metals and alloys is necessary to estimate their corresponding pouring temperature (Jain, 1986). Aluminum alloy casting has melting temperature of 660°C (Lindberg, 1997) with its corresponding pouring temperature range to be between 700°C-750°C. It was also stated by (Lindberg, 1997) that this melting temperature may be as low as 649°C.

Magnesium alloys have attracted an increasing interest in transportation, aeronautical and aerospace industries in the past decade because of their low density, but their mechanical properties and processing performances still could not meet the need of some important parts in vehicles and other important application fields due to their poor formability and restricted crip properties (Cottrey, 1975). Therefore a lot of ways are being investigated in the world to further improve the mechanical properties and processing performance of magnesium alloy (Beeley, 1974). Alloying is an important method used by many researchers. In recent years, Al-Mg alloy has emerged as a potential heat resistant Mg alloy. Despite its high affinity for oxygen, magnesium like aluminium is a stable metal with high resistance to corrosion at ordinary temperatures. Its chief attribute is its very low relative density (1.7) which makes it useful in aircraft and aerospace industries.

Initially, metals were used for adornments, combs, necklaces and bracelets for instance, which were made from gold and silver, the easiest of metals to extract from the ores, (Shingley & Mischye, 1979; Weast, 1969).

Alloying as discovered from history was first carried out by the Greeks and the Romans. It came about due to the discovery of more common and useful copper, which the Greeks and Romans learned to harden by alloying it with other metals to form bronze. Their beautiful bronze sculptures, coins, ornaments and utensils are legacies of casting of metals (alloying/bronze), (Shingley & Mischye 1979; Weast, 1969; Smithels 1967). Last of all came iron, the most common metal but the most difficult to work, unlike other metals whose relatively low melting points allows them to be cast in moulds, iron had to be forged. Nevertheless the Iron Age was truly the beginning of history, when man learned to shape thismetal; he began to change his life by making tools, utensils and in the distant future, machines (Davis, 1973). Adeke (1992) developed at coke brook dale, very often regarded as the birth place of industrial revolution. It was coke used to melt iron that gave the great investors the material from which they could make their machines.

In this paper, the efforts made in 'sand casting' Aluminum - magnesium alloys of the same size and shape at a selected pouring temperatures and rate is presented. The cast alloys were examined for mechanical properties. The aim is to determine the optimum percentage composition of magnesium in alloy at which these parameters could produce good quality castings.It has been stated (Lancer, 1981) that when pouring temperature is lower than optimum, the mould cavity will not fill the gate or riser will solidify too rapidly and intercept directional solidification.

On the other hand, higher pouring temperature causes shrinkage of the casting and mould warping (Davis, 1973). Above all, many casting defects result because the optimum casting conditions were not used during the casting process (Grill, 1982).

2. MATERIALS AND METHODS

This work primarily dealt with the effect of varying magnesium alloy compositions in an aluminiumalloy casting. Aluminium-Magnesium alloy (Al-Mg) was used as cast material. Aluminium alloy was chosen due to the fact that it was used widely in common engineering application like production of rivets, bolts, structural members, panel parts for moving airplanes and plants among other applications.

Common source of aluminium is from electric cables which are found to have a very high percentage composition of pure aluminium (99.99%). using a weighing balance, with the aid of a cutting machine the electric cables was cut into sizeable bits.

The Aluminum was now weighed on the weighing balance and the ratios of weights of aluminums to magnesium alloys wereobtained.

For this investigation, the casting parameters varied were the percentage of magnesium alloy composition, the pouring temperature and the pouring rate. Specimens of sand-cast Aluminum alloy were produced with the aid of wooden pattern. The standard casting procedure, which comprises of pattern making, molding, melting, pouring and cleaning/fettling was followed. Charging and melting was for 1 hour. Temperature measurement was done with the aid of a thermocouple and a multi-voltammeter device in which its reading was converted to degree celcius. The alloy was always heated to a temperature of 10^{o}C above the specified pouring temperature. This allows for temperature drops encountered during reloading and temperature loss during the time required for pouring of the castings to be compensated for. The same sizes and shapes were cast to present uniformity in measurement.

2.1. Preparation of the Aluminium-Magnesium Cast Alloy

The aluminium bits were weighed on a weighing balance to obtain the different samples and their respective weights; similarly the magnesium alloy was weighed on an electronic weighing balance to obtain their specific weights as shown in table 1. Having removed moisture and other impurities from the metallic crucible the mixture of aluminums and magnesium were loaded in the crucible and placed on the flames of fire in a foundry shop, for melting and uniform mixing to take place.

With the aid of a thermocouple with each of its junctions connected to the molten mixture and the multi-voltammeter respectively the thermoelectric voltage of the molten mixture was obtained to be 58.659mV and from the thermocouple tables, the corresponding super-heated temperature was found to be 760°C. At this temperature the molten metal in the crucible was removed with the help of tongs and the molten alloy was poured into already prepared sand molds. Finally, the castings were taken to the lathe machine where they were machined to their precise dimensions.

2.2. Determination of Pouring Speed

Pouring speed of molten metal, V may be defined as the flow of the metal per unit time. In determining the pouring speed, the parameter, V, is expressed as the distance of the ladle above the pouring basin per unit time of pouring the metal. This is expressed as:

$$V = \frac{H(cm)}{T(s)}$$

Where: V = pouring speed (cm/s); H = Height of ladle above pouring basin (cm); T = Time for pouring the molten metal (sec).

The sand mould for each specimen to be cast was placed on a mould board and the distance between the pouring basin and the ladle was measured as 30cm. The molten metal was then poured into the mould and the pouring time for each mould to be filled up was fixed at 12 seconds each for the five specimens so as to obtain a pouring speed of 2.5cm/s for the castings. The pouring temperature was maintained at 760°C.

2.3. Determination of Pouring Temperatures

The pouring temperatures of the Aluminum alloy castings were measured by a thermocouple. In the pouring ladle, the tip of the instrument was allowed to make contact with the base of the molten metal contained in it. The corresponding electromotive force value in mili-volts was measured and converted to temperature values in °C. For each casting, two temperature readings were noted and recorded accordingly. The first being the temperature reading at the beginning of pouring of the molten metal into the mould and the second being the temperature reading immediately the mould is filled up (ASME, 1996). The average of these two

temperatures calculated were the temperatures for the particular casting. This was done for the five castings to obtain a specific pouring temperature. The pouring speed was maintained at 2.5cm/s. The poured molten metal was allowed to solidify and cool, and then removed from the sand and the fettling operations were conducted on them using the normal methods.

2.4. Hardness Test

The Vickers hardness test machine was used on these samples due to the softness of the samples. Both high and low percentage magnesium alloys were tested to determine the effect of magnesium alloy concentration on an aluminium alloy.

The diamond indenter is a right pyramid form with asquare base and an angle of 136° between opposite faces. The diamond indenter was forced into the surface of the prepared material under the mass of 200 grams for 15 seconds.

For each sample at a different magnesium alloy percentage composition, five indentations were made; each indentation is at least 2mm from the other and the average value taken.

The diamond indenter made a square indentation and the diagonal lengths were measured by means of a microscope with a variable slit built into the eye piece. The width of the slit was adjusted so that its edges coincide with the corner if the indentation and the lengths obtained from a resolution counter geared to the movement of the slit. The reading was converted into Vickers hardness number (Hv) by reference to ocular chart corresponding to the applied load of 200g thereby preventing tedious calculations.

2.5. Compression Test

The compression test on the samples was carried out using the ELE compact-1500 compressive testing machine. The cubic samples were placed one after the other between the anvil and the applied load. The respective applied loads were recorded for each samples for all, failure of the compressed samples were also recorded accordingly.

2.6. Metallographic Examination

The above examination was essential since it was targeted at checking/observing and analyzing the effect of vibration on the samples. The samples were first grinded on silicon carbide papers of grid 60, 120 followed by 320, 600 and 800 to smoothen the surface. Each sample was rinsed in water after each grinding operation to avoid introduction of foreign particles to the next series of paper and polished on nylon polishing cloth, with the application of gamma aluminums powder with particular sizes of 0.95 microns on a metaserv polishing machine. The polished samples were rinsed in water thoroughly and dried before etching for 30 seconds in tucker's reagent of composition 0.5% hydrofluoric acid and 2.5% hydrogentrioxonitrate (iv) acid and water. The microstructures of the etched samples were observed under the objective of the metallurgical microscope and whenever a satisfactory image of the specimen was observed through the eye piece, the structure observed was considered.

The aim as statedearlier was to see the effect of varying percentage compositions of magnesium on the microstructure of the samples; the sizes of the grains were measured. Intercept procedure method was employed in measuring the approximate grain size, measurements were carefully taken.

Where, field diameter (Ø) = 330u

N_m = mean grain measured.

$$N_m = \frac{\text{Summation of all grain along the intercept}}{\text{Number of grain}}$$

$$\text{Hence, } N_m = \frac{EN}{EN_1}$$

$$\text{Approximate grain size} = \frac{Ø \quad \text{(Field diameter)}}{N_m \quad \text{(Mean grain)}}$$

Where, N_m is as computed above.

3. RESULTS

This chapter presents the results of all the tests, carried out (Hardness, Compressive strength and Metallurgical examination) on the different samples of varying percentage composition of magnesium alloy (3.33%, 6.67%, 10.00% 13.33% and 16.67%).

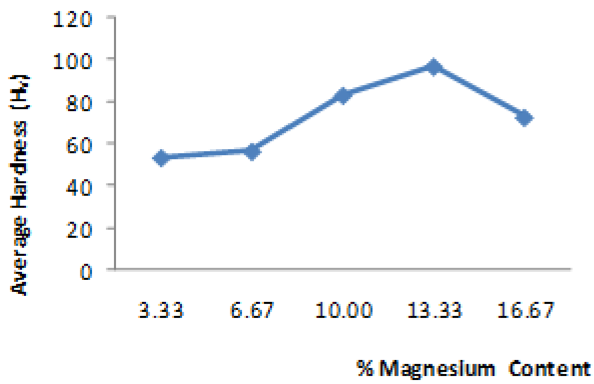

Figure 1

Graph of average hardness against percentage magnesium content

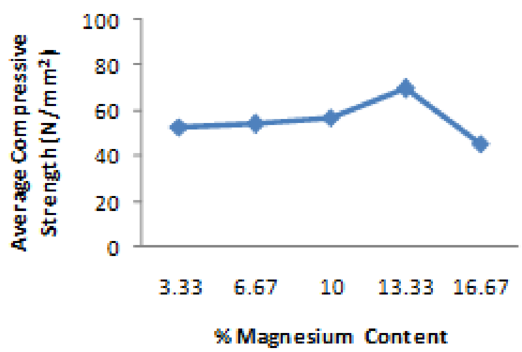

Figure 2

Graph of Average compressive strength against Percentage Magnesium Content

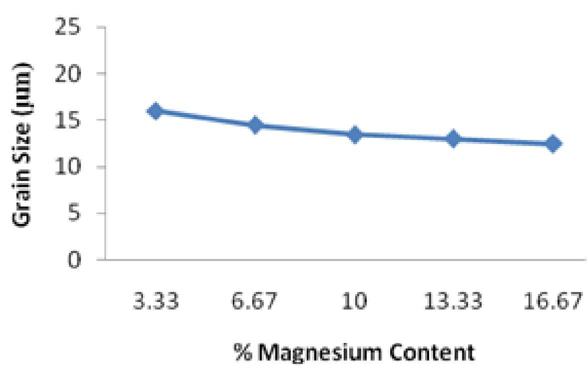

Figure 3

Graph of Grain size against Percentage Magnesium Content

3.1. Results of Vickers Hardness Test

The results of the hardness tests carried out on all the samples of different percentage composition of magnesium alloy are presented in table 2. The graph of Vickers hardness (H_v) number against the percentage composition of magnesium in the different samples is plotted in figure 1.

3.2. Results of Compression Strength Test

The results of compression strength test carried out on all the samples of different percentage composition of magnesium are displayed on table 3. The graph of average compressive strength against the different percentage composition of magnesium of the different samples is plotted in figure 2.

3.3. Results of the Metallographic Examination

The observation made on the microstructures of the etched specimen presented an interesting result. The grains were measured and the different grain sizes obtained are presented in Table 8. The graph of the grain size against percentage composition of magnesium during solidification was plotted as shown in figure 3.

Table 1

Compositions of the prepared alloy

SAMPLE	MAGNESIUM (g)	ALUMINIUM (g)	COMPOSITION OF MAGNESIUM (%)	COMPOSITION OF ALUMINIUM (%)
A	3	87	3.33	97.67
B	6	84	6.67	93.33
C	9	81	10.00	90.00
D	12	78	13.33	86.67
E	15	75	16.67	83.33

Table 2

Results Obtained for Vickers Hardness Test

Distances (mm)	D_1 (mm)	D_2 (mm)	D_m(mm)	HARDNESS H_V	AVERAGE HARDNESS A_V H_V	PERCENTAGE COMPOSITION OF MAGNESIUM (%)
2	10.50	10.50	10.50	54		
4	10.00	10.00	10.00	53	53.3	3.33
6	10.00	10.00	10.00	53		
2	13.00	13.00	13.00	56		
4	13.00	13.00	13.00	56	56.3	6.67
6	13.50	13.50	13.50	57		
2	17.00	17.00	17.00	82		
4	17.50	17.50	17.50	84	83.0	10.00
6	17.50	17.00	17.25	83		
2	19.00	19.00	19.00	96	96.7	13.33

4	19.50	19.00	19.25	97		
6	19.00	19.50	19.25	97		

2	15.50	15.00	15.25	73		
4	15.00	15.00	15.00	72	72.5	16.67
6	15.00	15.00	15.00	72		

Table 3

Average Compressive Strength for Specimen A

Load (kN)	**D_1 (mm)**	**D_2 (mm)**	**Area (mm^2)**	**σ (N/mm^2)**	**Average σ (N/mm^2)**
4	8.0	8.2	201.06	19.89	
8	8.2	8.6	211.24	37.87	
12	8.6	9.1	232.35	51.65	52.72
16	9.1	9.5	260.16	61.50	
20	9.5	10.1	283.53	70.54	
24	10.1	12.3	320.47	74.89	

Table 4

Average Compressive Strength for Specimen B

Load (kN)	**D_1 (mm)**	**D_2 (mm)**	**Area (mm^2)**	**σ (N/mm^2)**	**Average σ (N/mm^2)**
4	8.0	8.9	201.06	19.89	
8	8.9	9.4	248.85	32.15	
12	9.4	9.7	277.59	43.23	
16	9.7	10.0	295.59	54.13	54.00
20	10.0	10.3	314.16	63.66	
24	10.3	11.1	333.29	72.00	
28	11.1	11.7	387.08	72.33	
32	11.7	12.5	430.05	73.41	

Table 5

Average Compressive Strength for Specimen C

Load (kN)	**D_1 (mm)**	**D_2 (mm)**	**Area (mm^2)**	**σ (N/mm^2)**	**Average σ (N/mm^2)**
4	8	8.5	201.06	19.89	
8	8.5	8.8	226.98	35.26	56.88
12	8.8	9.3	243.28	49.33	

16	9.3	9.8	271.72	58.88
20	9.8	10.4	301.72	66.29
24	10.4	10.9	339.79	70.63
28	10.9	11.3	373.25	75.02
32	11.3	11.8	401.15	79.77

Table 6

Average Compressive Strength for Specimen D

Load (kN)	**D_1 (mm)**	**D_2 (mm)**	**Area (mm^2)**	**σ (N/mm^2)**	**Average σ (N/mm^2)**
4	8	8.3	201.06	19.89	69.6
8	8.3	8.7	216.42	36.97	
12	8.7	8.9	237.79	50.46	
16	8.9	9.2	248.85	64.30	
20	9.2	9.6	265.90	75.22	
24	9.6	9.8	289.53	82.89	
28	9.8	10.0	301.72	92.80	
32	10.0	10.3	314.16	101.86	
34	10.3	10.6	333.29	102.01	

Table 7

Average Compressive Strength for Specimen E

Load (kN)	D_1 (mm)	D_2 (mm)	Area (mm^2)	σ (N/mm^2)	Average σ (N/mm^2)
4	8	8.4	201.06	19.89	45.45
8	8.4	9.0	221.67	36.09	
12	9.0	9.5	254.47	47.16	
16	9.5	9.7	283.53	56.43	
20	9.7	10.0	295.6	67.65	

Table 8

Grain Size Measurement

3.33% Magnesium Alloy Composition						
N_1	N_2	N_3	N_4	N_5	N_A	Grain Size
21	21	20	21	20	20.6	16.02
6.67% Magnesium Alloy Composition						
N_1	N_2	N_3	N_4	N_5	N_A	Grain Size

23	23	22	23	23	22.8	14.47
10.00% Magnesium Alloy Composition						
N_1	N_2	N_3	N_4	N_5	N_A	Grain Size
24	25	25	24	25	24.6	13.41
13.33% Magnesium Alloy Composition						
N_1	N_2	N_3	N_4	N_5	N_A	Grain Size
25	25	26	26	25	25.4	13.0
16.67% Magnesium Alloy Composition						
N_1	N_2	N_3	N_4	N_5	N_A	Grain Size
26	26	27	27	27	26.6	12.41

4. DISCUSSION

4.1. Hardness Test Results

Analysis of the hardness of the specimens reveals that the hardness of the specimens increased with percentage composition of magnesium of the samples up to the 13.33% point. After which the hardness of the specimen dropped. A decrease in hardness implies an improvement in ductility of these specimens, which means that it can be deformed easily. The effect of varying the percentage magnesium content in aluminium – magnesium alloy shows an increase in the strength and hardness of the sand cast alloy this is accompanied with a decrease in ductility and impact resistance. The increase in hardness from 3.33% to 13.33% can be explained according to (Davies, 1983) as the suppression of the columnar and dentritic growth and the formation of small equiaxed grains.

4.2. Compression Test Result

From the compression test carried out on the specimens produced at varying percentage magnesium content compositions, the extent of grain refinement depends on the percentage composition of magnesium in the alloy, hence the specimens which solidified under low percentage compositions brought about coarsening of grains which reduces the compressive strength of the specimens (Adeke, 1992). It can be observed from the tables 3 to 7 that there is a variation in the maximum magnitude of load at which failure/fracture takes place in a specimen under compression. In the range of magnesium additions tried, the sample containing 13.33% sustained the highest magnitude of the applied load in 34KN. Furthermore, the average compressive strength of the samples increased with a proportional increase in the percentage composition of magnesium in the alloy up to the sample with 13.33%; where it hence forth experienced a sharp decrease in compressive strength.

4.3. Metallurgraphic Examination

Optical microscope was used in the micro structural studies of the sand cast Aluminium – magnesium alloy and this presented a very interesting result as shown table 3 and figure 3. It was observed that there was reduction in grain size as the percentage composition of magnesium increased from 3.33% to 13.33% in the alloy, this is attributed to the suppression of columnar and dentritic growth in the specimen and formation of equiaxed grains. However above 13.33% the grain size suddenly increased in size, this is due to the coarsening of grains. The implication of these is that at varying percentage composition of magnesium in the alloy, there was a reduction in grain size; resulting in an increase in compressive strength and hardness for 3.33% to 13.33%. Therefore, the smaller the grain particles, the higher the compressive strength and hardness and vice versa.

5. CONCLUSION

From both the quality and mechanical property assessments, it was found that for Aluminum alloys the optimum pouring temperature range is between 700ºC and 750ºC. This is the region where good quality casts are produced with good mechanical properties. Percentage magnesium content affects the mechanical properties and microstructure of aluminium- magnesium alloy.(Hardness, Compressive Strength and Grain size)

1. There was an improved hardness and compressive strength (Mechanical properties) with corresponding increase percentage magnesium content in the alloy from 3.33% to 13.33%.
2. Grain refinement was achieved, the increase in magnesium alloy compositions showed an appreciable increase in grain refinement.

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